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Supporting Information for

"Metamaterial inspired enhanced far-field transmission through a subwavelength nano-hole"

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In this "Supporting Information", the details of our design simulations, nano-fabrication technique and experimental methods (belonging to Section "**2 Methodology**" of the RRL) are given:

2.1 Design Simulations We started our analysis with numerical simulations of the magnetic metamaterial unit cells. We inserted the metamaterial unit cell in a simulation domain and assumed the unit cell to be infinitely periodic at the lateral directions. The commercial software CST-Microwave Studio, which uses the full wave finite integration method, helped us to see the response of the photonic metamaterial designs. We used the program's frequency domain solver with unit cell boundary conditions. Metamaterials composed of shaped metallic resonators placed on a substrate. Their actual parameters such as metal loss, coated metal thickness, resonator side length, strip width, and arm length of these structures should be identified by the help of experimental data. We used the data given in the literature for the metal characteristics and performed the design simulations. As the next step, we tried to fabricate the arrays of the resonators, and we paid specific attention to achieve the structure parameters as designed.

2.2 Nano-fabrication Firstly, we prepared the sapphire substrate on which the metallic resonators would be printed. It was diced to 7 mm × 7 mm dimensions, cleaned in acetone, isopropanol, deionized water consecutively, and dried by using a nitrogen gas gun. The sample was dehydrated on a hot-plate at 180 °C for 1 minute and coated with polymethyl methacrylate (PMMA-950K-A2) high resolution positive resist via a spinner machine to achieve a 150nm thickness. The e-beam exposure step starts with the design of the exposure structures and dose tests. In the Raith e-beam lithography computer aided controller program, we drew the U-shaped resonators as a composition of single pixel lines. For the dose tests, a two-dimensional array of split ring resonator (SRR) arrays with slightly varying parameters was organized. A dose test exposure was performed at 15 kV acceleration voltage, and the sample was inserted into a developer solution of 1:3 ratio MIBK: H_2O and kept there for 45 seconds. The next step was metallization, and the sample was coated with silver (Ag) via an e-beam evaporator machine. The final steps were the lift-off and scanning electron microscopy (SEM) inspection. We determined the optimum dose for the designed dimensions. By using these optimum dose test results, we fabricated the SRR array coated sample, as shown in Fig. 1(b).

2.3 Experiment The transmission measurements of the samples were performed by using a homemade transmission setup. Incident white light was passing through a cube polarizer and focused on the SRR printed area via a 20× objective. We collected the light with a 50× objective and by the aid of a mirror, we sent the beam to a CCD camera. We found the position of the SRR array on the sapphire sample and then centered the light beam on that area. Then, we removed the mirror and allowed the light to go to the lens and multimode fiber. For the two incident polarizations, the signal was measured by a visible spectrometer. First, we measured the calibration data by moving the sample a few hundred micrometers so that the beam was on the bare substrate area. Then, we moved the sample back to the initial position and found thereby the transmission response. We used a spectrometer that can measure the 600–1000 nm band in these measurements, and we extended our measurement range to include 900–1700 nm band. In our test measurements, we characterized several SRR arrays with different parameters and observed the shift of electrical resonance as was expected.

2.4 Discussion We would like to discuss a few points related to the fabrication and simulation. For the e-beam lithography fabrication technique, the resonator parameters can be different from the designed ones on the order of 5 nm. In addition to this, the measured structure parameters can be a few nm different from the real ones due to the SEM image precision limit. We observed that for each of the printed SRR we had a different set of parameters in our array. The parameters varied at most 5 nm from one SRR to another at different regions of the array. Therefore, in our simulations we had to find out a set of average SRR parameters that gave the same response as the experimentally characterized one. The unit cell of the average SRR whose transmission response is close to the measured SRR array is shown in Fig. 1(a). We took the substrate thickness in the simulations as $t = 150$ nm while it was 1 mm in the experiments. In the simulation domain, we observed that using a substrate thickness larger than 150 nm does not change the resonance frequency of the SRR array. Thereby, in all of our simulations, we used 150 nm thick substrate instead of a 1 mm one.